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Rural electrification and energy poverty: Empirical evidences from Brazil

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ABSTRACT

The aim of this article is to evaluate the impact of rural electrification on the reduction of energy poverty in Brazil through the analysis of 23,000 rural domiciles or rural properties between the years 2000 and 2004. The results indicate a fast change in the profile of energy consumption and a reduction of energy poverty. This new approach works as a complement, among other variables, to analyze and quantify the real economic, social and energy impacts in rural electrification programs, generally applied in developing countries.

Contents

1. Introduction

The absence of commercially supplied energy in a society, especially electricity, tends to accentuate the existence of social asymmetry in conditions of living. This can take the form of increased poverty, lack of opportunity for development, migratory flow to large cities and a society's disbelief regarding its own future. There is a general belief that, with the arrival of electricity, such societies might acquire a higher degree of economic sustainability and a better quality of life.

It is estimated that one-third (1/3) of the world's population, amounting about 2 billions of people around the world, has no access to electric energy. Half of this population lives on the African continent.

One of the paths toward economic sustainability refers to the availability of access to regular electric energy. Such access is a key element for the economic development of the rural environment and for the reduction of poverty. However, expanded access to electric energy has shown slow progress worldwide, especially due to the high costs associated with extending grids and developing decentralized systems by which offers power.

The public policies whose objective it is to reduce poverty and inequality[1] necessarily permeate education and health matters. Both are directly related to the availability of electricity, mainly

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[1] According to Scheikman [2], Brazil is not a poor country, but indeed a rich one with extremely unequal distribution of income. Its inequality is essentially stable throughout time. The income of the 10% richest amounts to roughly 50% of the total income of families, whereas at the other extreme the 50% poorest barely appropriate 10% of the total income. This disproportional distribution of income has occurred for at least 30 years, crossing various institutional, political and economic cycles.

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Table 1
Main reform measures worldwide.

Reform measures	Kenya (1996)[a]	Senegal (1997)	Zamhia (1994)	Philippines (2000)	Thailand (1990)	Vietnam (1995)	Argentina (1990)	Peru (1991)	Chile (1980)
Liberalization	×	×	×	×	×	×	×	×	×
Independent power producer	×	×	×		×	×			×
Compartmentalizing of grids	×	×		×			×	×	×
"Corporatization"	×	×	×	×	×	×			
Commercialization									
Privatization			×	×	×	×	×	×	×
Regulatory agency	×	×	×	×	×		×	×	×
Rural electrification agent		×	×	×	×	×			×

Source: Haanyka [6] and GNESD [5].
[a] Start of reform.

insofar as the rural environment is concerned. Electricity is one of the pillars on which education and health lean. As such, the universalization of the access to electric energy in the world is of fundamental importance for the eradication of poverty and reduction of social inequality.

Poverty should be the focus of a range of specific public policies, aimed not only at mitigation, but also at eradication. Lack of access to modern sources of energy aggravates poverty, particularly in the countryside, where opportunities are scarce. The establishment of public policies aimed at the eradication of poverty should include the expansion of access to energy, in particular to electricity, taking into account, mainly, social interrelations [1].

This article is divided into six sections. In Section 2, the theme of rural electrification and the reform framework of recent years are presented. The section is subdivided so as to deal with the lessons learned from the international and Brazilian experiences, respectively. Section 3 discusses, not extensively, the use of alternative technologies in rural electrification. Section 4 presents the considerations about methodological aspects, fieldwork and data utilized. Section 5 exposes the case study and its respective analysis of energy poverty in Brazil. Finally, Section 6 offers conclusions and recommendations.

2. International and Brazilian context

Nowadays [2,3] the world recognizes the importance of energy services for reaching the Millennium Goals,[2] especially emphasized in session nine of the Commission for Sustainable Development (CSD-9), which asserts the following UNDP [4]:

> "To implement the Millennium Goals, the international community has to halve the proportion of people living on less than US$1 per day by 2015, with access to energy services being a prerequisite. Increased access to safe and reliable energy is a fundamental inducer to reduce poverty..."

Over the last two decades, developing countries have implemented a variety of initiatives to reform the power sector, with differing results. However, such reforms merely overlapped with the scant progress made with respect to providing access to regular electric energy in countries considered to be poor [5].

Contrary to expectations, some specialists assert that few of the worldwide reform projects have resulted in significant improvement of the provision of electricity. In some cases, one may even observe an aggravation of social conditions, the outcome of which was an increase in social poverty,[3] as well as in energy poverty,[4] It is thus preoccupying that in some cases such reform movements have incurred a deterioration of the quality and reliability of energy services, especially concerning sub-Saharan Africa and parts of Latin American, the Caribbean and southern Asia.[5]

Table 2
Electrification level and consumption per capita.

Countries	Electrification level	Consumption per capita (kWh/year)
Bangladesh	31%	96 (2002)
India	43%	379
Nepal	15.4%	47
Pakistan	52.9%	321
Sri Lanka	62% (2001)	255
Cambodia	15.8% (1998)	78(1999)
Indonesia	53.4% (2001)	345
Laos	33% (2002)	113(1999)
Myanmar	5%	71
Malaysia	90%	2474
Philippines	54% (2002)	454
Singapore	100%	6641
Thailand	98.5% (2002)	1440 (2002)
Vietnam	77.4% (2001)	285(2001)

Source: GNESD [5]. *Obs*: Data from 2000.

2.1. Rural electrification and reform worldwide

The current wave of power sector reform in the world began in Chile in the 1970s according to a strongly based market vision. The nature and extent of the reforms depended on regional circumstances and influence. Generally speaking, reforms were directed toward structural changes and/or privatization. Structural changes included the separation of generation, transmission and distribution activities. In some cases, reform was restricted to separating the generation activity from the liberalization of access to transmission lines,[6] and privatization [6].

Prior to the aforementioned reforms, in various countries throughout the world (pre-reform) some actions were needed to develop a favorable political and institutional framework for the reforms that were to come. Among these measures, a legal and institutional structure had to be built.

Table 1 highlights the main reform measures in the world, especially in the developing countries of Asia, Africa and Latin America. It is worth noting that all of the countries listed undertook the liberalization of their markets. Most of these countries installed a regulating agency, which opened the way to the appearance of

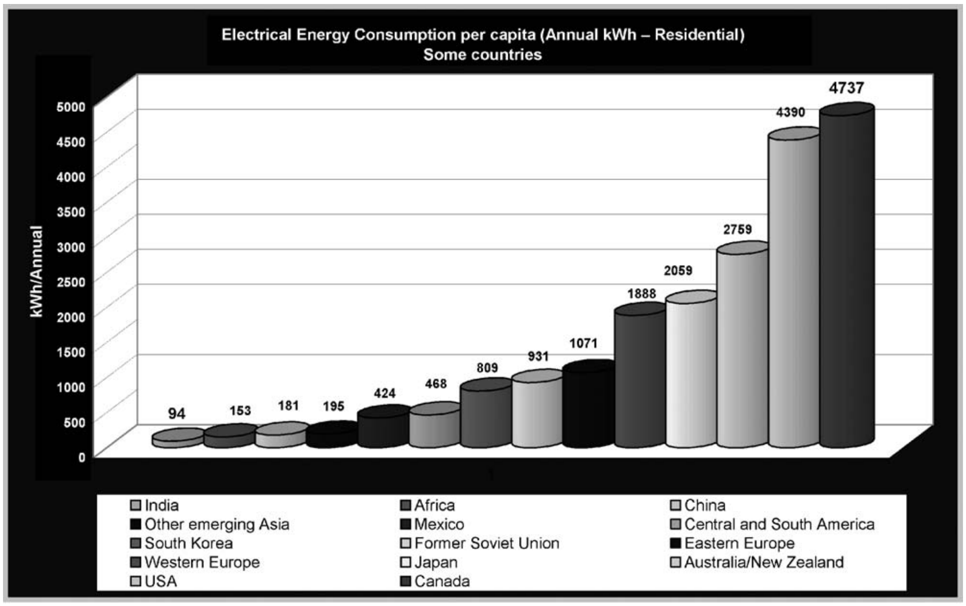
[2] The Millennium Goals were launched in September 2000. Eight goals are measured by indicators. The main objectives are to: eradicate poverty, improve health and promote peace, human rights and environmental sustainability [4].

[3] Poverty is traditionally linked to an insufficient amount of income required to satisfy basic necessities, like: food, housing, health, transportation and education.

[4] Energy poverty can also be understood as a lack of choice in access to energy that is adequate, safe, and reliable for economic and human development.

[5] Despite the recent effort to increase the number of persons with access to electric energy, this rate still remains lower than (household) population growth for many countries in sub-Saharan Africa [5].

[6] The opening of access to transmission facilitated the entry of independent power producers (IPP).



Graph 1. Electric energy consumption per capita. *Source*: International Energy Outlook [7]. *Obs*: Data from 2002.

the Independent Energy Producer. In some cases, an entity was put in charge of rural electrification.

As already mentioned, the worldwide reforms led to differentiated results. Despite the efforts, few of them led to advances in electrification levels, which still showed extremely low annual per capita electricity consumption (Table 2). This indicates how far these countries are from the consumption patterns of the developed countries. The consumption of electric energy per capita may be considered as a reference for well-being (a proxy), which assumes that the highest consumption per capita is, in fact, the highest the stage of development. As such, countries such as Nepal (47 kWh/year) and Myanmar (71 kWh/year) get a classification of 0.530 (2008) and 0.585 (2008) in the Human Development Index, respectively. Such countries are at the threshold of low human development, as based on the results of the study. For purposes of illustration, Brazil's consumption of electric energy is 2400 kWh/year per capita (2008), placing the country at an average position in human development, with an index of 0.807 (2008).

Graph 1 highlights the household per capita consumption of electric energy per year in some countries. Low consumption of electricity can be observed in India (94 kWh/year), on the African continent (153 kWh/year) and in China (181 kWh/year). By contrast, high consumption is seen in countries like the USA (4390 kWh/year) and Canada (4737 kWh/year). When considering these two extremes, it is useful to emphasize Canada's consumption as being 50 times greater than India's in the year 2002. According to International Energy Outlook (2005), in 2025 the same relation will be 18 times greater (India 308 kWh/year and Canada 5670 kWh/year). That is, while the proportion of consumption between countries will be lower, consumption will remain highly concentrated in the countries that are nowadays considered to be developed.

According to Yeager [8], who has delved into the analysis of the relation between energy and development, the author puts forward a distinction between four dimensions: survival, basic quality of life, amenities and internal collaboration. To establish the fundamental conditions for education and the environment, the author suggests that the consumption of electric energy must be higher than 1000 kWh/year per capita. With anything lower than this marker, only the basic conditions and, at the extreme, survival, would be "guaranteed". Still according to the author, policy makers ought to seek a level of annual electric energy consumption above 1000 kWh per capita, since this level indicates an improvement in the social conditions of the population studied (Fig. 1).

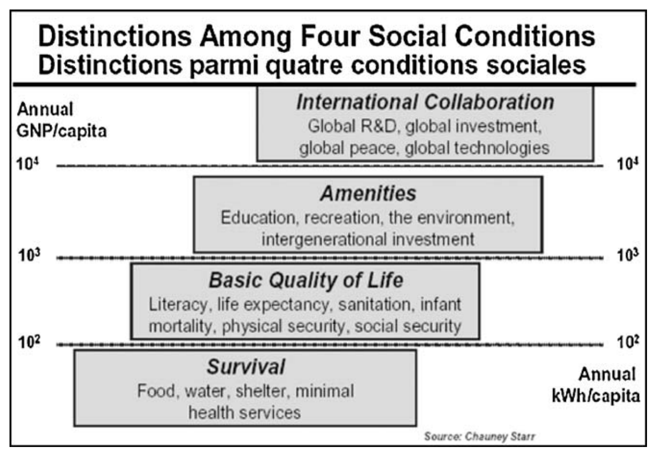


Fig. 1. Social conditions and electric energy consumption. *Source*: Yaeger [8].

As for the demand side, it is common knowledge that the target population's income limitations restrict the possibility of reaching the consumption level indicated. By contrast, on the supply side, these restrictions suggest to cultural and climatic characteristics, and to technological and cost limitations.

Table 3
Rate of electrification per region.

Electrification level/regions	Urban	Rural	National
Developing countries	85.6%	51.1%	64.2%
East Asia/China	98.5%	81.00%	86.9%
Latin America	98.00%	52.4%	86.6%
South Asia	68.2%	30.1%	40.8%
Africa	63.1%	16.9%	34.3%
World	**91.2%**	**56.9%**	**72.8%**

Source: GNESD [5]. *Obs*: Data from 2000.

Considering again the classification proposed by Kurt Yeager [8],[7] and observing the data in Table 2 and Graph 1, it would be possible to issue a warning on just how far the majority of countries listed are with respect to the "Amenities" threshold. Bearing in mind that, generally speaking, the data are aggregated for the rural and urban areas, it is possible to assert that the urban reality insofar as per capita consumption is concerning, it is quite superior to the rural average. As such, the latter lies even further from a level of individual consumption above 1000 kWh/year.

Table 3 emphasizes the electrification rate per region (urban and rural). One observes how great an effort the African continent needs to reach universalization of the access to regular electric energy, especially in rural areas where only 16.9 percent of the population is served. Despite major effort in recent years, considerably leading to penetration of electric energy in China and East Asia, they still needs to endeavor toward universalization, as also does Latin America, especially in rural areas.

According to Albouy and Nadif [9], the reforms performed in the world have brought to light the impacts more visible and immediate, such as the increased rates for many users, considering the reduction of subsidies built into rates and lower commitment of the governments in rural electrification programs. On the other hand, indirect impacts are few studies, such as the best customer service, the reduction of technical and non-technical losses, and improvement in government finances. Many of these indirect aspects, regardless of the outcome being positive or negative, the data are limited for most countries, thus restricting to a broader assessment

Still Albouy and Nadif [9], in a temporal analysis, it was found that in countries, and also in sectors of infrastructure, the sources of inefficiency were due to institutional issues, i.e., government interference, regressive subsidies, and in some cases, corruption.

2.2. Rural electrification and reform in Brazil

Prior to the reform process of the Brazilian electricity sector, the concessionaires were using the resources of state governments with scattered programs of rural electrification in areas with higher population concentrations or even the conjunction of factors of consumers with a greater economic and political power to claim.

This behavior occurred in the absence of a national policy for rural electrification, opening up space, so that concessionaires could play a stronger business, limiting attendance to those who have greater economic attractiveness of the investment.

The process of sector restructuring was guided to maximize the values of the companies to be privatized, in parallel with the reduction of the obligations of the concessionaires. At that time, little attention was given to the process of expanding service to low-income population, as well as rural areas.

Privatization and deregulation as a way to reduce the presence of the State in the economy, have become mandatory in the rhetoric of the Brazilian government in the 90s through these instruments aimed to introduce greater efficiency in electric sector. In contrast, this movement led to a new regulation and not to deregulation, as well as a renewal of the normative role of the State, but not lowering them.

The creation of the regulatory agency was instrumental in the establishment of market rules, embedded in a redirection of state functions in the first round of reforms (1995–2002). In the second round of reforms that began in 2003, the expansion planning has been taken, in particular, consider seeking the assistance the country's electricity, considering the supply crisis in the country in 2001,[8] and encourage investment in the expansion of transmission lines and in the power plants including renewable energy sources, such as SHP, biomass and wind. The regulatory agency has set the standards for low-income consumers, with differentiated tariffs. And in parallel, it was established a timetable for universal care until 2015, being penalized dealers with up to 10% reducing the tariff revision even those that do not meet the deadlines.

Developing countries have little tradition in investing in R&D in general and in energy R&D in particular. Often R&D efforts are adaptive following externally developed technologies. Total national expenditures in R&D in developing countries hardly represent a significant share of their GDPs. In 1994 the average was about 0.65% in developing countries and 3% in industrialized countries. India and Brazil, for example, dedicate a little over 0.5% of their GDP to R&D activities, much less than South Korea and several industrialized countries. In per capita terms total Brazilian R&D expenditure in year 2000 were US$ 80.40, more than 10 times smaller than the US per capita expenditure and 5 times less than South Korea. Nevertheless, several developing countries have over the years created and supported research institutions with the purpose of providing technical (and in fewer cases, scientific) assistance to the existing electricity utilities [10].

In the process of privatization of the sector, many companies have been acquired by multinational groups, in which significantly reduced investment in research and development. Facing that, it was established by the Brazilian government that resources between 0.75% and 1% on net sales of generation concessionaires, transmission and distribution of electric energy, would be used to fund programs and projects in the energy area. The emphasis was on linking the direct expenditure of firms in R&D and the definition of a comprehensive program to address the long-term challenges in the industry, such as alternative energy sources with lower costs and better quality, waste reduction, energy efficiency, besides of stimulating the increase of competitiveness of national industrial technology.

According to ABRADEE [11], in Brazil the percentage of annual revenues that is dedicated to R&D varies from 0.5% (distributing utilities) to 1% (transmission and generating utilities). Half of these values are spend by the utilities themselves in internal R&D projects; the other half is collected by the CTEnerg fund. Distributing utilities have to invest 0.5% of their annual revenues in end-use energy efficiency projects. Therefore, end-use efficiency programmes are only implemented by distributing utilities. In 1998 about 0.4% of electricity sales was invested in energy R&D programmes, with the approval of Law 9.991/00[9] and the creation of CTEnerg fund, this percentage in year 2003 raised to 1.1%.

The 1990s were a watershed decade for Brazil's power sector, which saw deep changes brought to its structure, behavior and performance. In a reform environment, a regulating entity was created, that is, the National Electric Energy Agency (*Agência Nacional de Energia Elétrica*—ANEEL). At the time, ANEEL oversaw a series of public service concession contracts for the distribution of

[7] It is interesting to note that in the literature there is still no consensus on the amount of energy needed to guarantee human survival. This question is extremely complex, given the diversity of factors affecting the planet's regions in different ways, such as: temperature, gender, time length, age, and social customs, among others.

[8] It is a fact that electric energy service is present in most Brazilian households, by which it is still well ahead of other services such as piped water and fixed telephones. By contrast, it must be observed how many people still do not have access to electricity, especially in rural areas, when considering that the offer of a safe and continuous amount of electric energy is of fundamental importance to bring a movement for rural development in the country.

[9] In year 2000 the Bill 9.991/00 approved by the Brazilian National Congress made explicit provisions for a public benefit fund CTEnerg. This Bill allocates part of the 1% annual utilities revenues for CTEnerg and other part remains with utilities (generation, transmission and distribution), being spent in efficiency and R&D programs. Electric utilities remain responsible for the design and implementation of these programs under the Regulator's supervision, as previously.

Table 4
Non-electrified households per region (urban and rural).

Regions	Urban	%	Rural	%	Total	%
North[a]	31,765	1.29	–	–	31,795	1.29
Northeast	110,077	0.87	941,917	19.7	1,051,994	7.45
Centre-West	13,474	0.38	88,410	2.47	101,884	2.84
Southeast	30,472	0.14	111,192	0.5	141.664	0.63
South	**23,948**	**0.3**	**80,475**	**1.02**	**104,423**	**1.2**
Brazil[b]	**20,908**	**0.43**	**1,269,247**	**2.58**	**1.479.252**	**3.01**

Source: IBGE [14].
[a] *Obs*: Data from the North Region excludes the rural areas of all the Unit components of the Brazilian Federation, save for the State of Tocantins.
[b] *Obs*: The data for Brazil excludes the rural areas of Rondonia, Acre, Amazonas, Roraima, Para and Amapa States.

electric energy. However, an unexpected development for concessions was the establishment of rural (or urban) electrification goals, i.e. the execution of rural electrification projects were conducted on a "voluntary" basis.

In this period, there was a reduction in the pace of rural electrification initially. By the end of the decade, an effort was made again to attend to the deficit still present in Brazil. In a federal government decision, conditions were developed to reach 1,000,000 rural households with an investment forecast of about 1 billion dollars, with a counterpart on the part of the beneficiary.

In 2003, the government program "*Luz para Todos*" ("Light for All") was launched with the aim of universalizing the access to all Brazilian citizens by 2010. The estimated investment was US$ 12 billions, with no counterpart on the part of the beneficiary. According to Fidelis and Rosa [12] "the Light for All" Program is responding to historic demands set forth by grassroots movements and striving to redeem the social debts owed to this segment of the population.

The main objective of "Light for All" is social inclusion through access to electricity supply. It is an important step towards achieving the much-longed-for dream of universal access to electrical energy services. Besides accelerating universal access to electric energy, Light for All will allow for the generation of about 115,000 indirect and direct jobs, according to an estimate by the Ministry of Mines and Energy [13].

According Ministry of Mines and Energy the Universalization Program will be achieve by extend transmission lines using low-cost technology and decentralized power generation using local and renewable sources.

It should be noted that current Universalization Program was born with own fund, established by part of resources for grant and part to funding. This was possible considering that the costs of the program were distributed to all residential consumers in the country, estimated at 42 million. Considering the amount of participants, it was possible to provide support funds to the Program without imposing, overly, the already consumers. The Program for the Universalization of Service "*Luz para Todos*" does not impose to the final consumer, i.e., no connection costs to the user. For this, the concessionaires make use of heavily subsidized government funding, where 80% of the funding applied to grants (72% federal and 14% state and municipal) and 14% of funding is provided by the concessionaires that can pass the costs on the charges, with a cap impact of 8%. The government resources are originated from the Energy Development Account (EDA) and the Global Reversion Reserve (GRR), and these funds are fed with resources collected in the monthly energy bills of all consumers in the country.

It is important to note that at first, the reforms performed in the sector incurred in reducing the speed of electric service, particularly in rural areas. This reduction was due to the undefinition of responsibilities regarding the care of rural areas. However, the coverage rate in rural areas has improved, when comparing the first (1991) and after reform (2008), from 49.43% to 97% in 2008. This positive result can be partly explained by the reduction of the rural population in the country, around 5 million Brazilians, and together with the greater effort made by the government in this decade, particularly by bringing forward the goal of universalization of the electric service in the country up to the year 2010.

Brazil's residential sector has a share of 25.2% of the total consumption of electricity, distributed among 42.5 million households. In the whole country, 97% of households have access to electric energy on a regular and safe basis. Whereas Brazil's urban sector amounts to 99.57% of household service, in the rural area this index reaches to a level of 97.42%, with a contingent of those without regular electric energy reaching an estimated 10.5 million people in rural areas in 2003. Table 4 shows that the lack of service is more concentrated in Brazil's rural areas.

It is should be pointed out that in Brazil, the first cycle of sector reforms was driven by the ideal of the minimal State. In the second cycle of reforms, begun in 2003, the actions were driven by the maintenance of a regulative state. This latest cycle has also seen an initiative to resume a planning capacity that involves the creation of a new institutional arrangement with a broader social agenda.

Although the big effort on the aiming of universalization of the access in the country, having connected around 10 millions of Brazilians, during the last 6 years, today the biggest challenge is to attend the Amazon, mainly isolated communities, for this it is necessary the articulation of the decision makers with their utilities, regulatory agencies, university and research centers for the development of cleaner technologies and improvement managements models, respecting the cultural, economic and environmental questions for the use of renewable technologies of decentralized generation or individual generation, specially solar photovoltaic, thus searching to speed up the electrification process.

3. Use of alternative technologies in rural electrification

Renewable energy systems are increasingly being viewed as a favourable option for providing power to isolated communities or homes, collective or private farms, etc. Technology options include small-hydroelectric plants, biomass-powered generators, small geothermal, solar thermal, wind turbines, and hybrid systems which may be connected to the electric grid.

The nonconventional technologies generally provide electricity at a higher cost and with a poorer quality (lower voltage, less hours of service). But they have been an attractive alternative where extending the grid is too costly because of the distance from the existing grid or the high dispersion of dwellings. Both these causes have increased the marginal cost of rural electrification in Brazil.

New technology must be created or adapted in accordance with the economic and geographical conditions of each individual country and each individual company within those countries. Thus, the implementation of these technologies will depend especially, on a scientific research program that targets the total use and reuse of all constituents of the system within a geographic

region. Eco-technologies regionally developed can enable conversion of wastes to resources and by-products based on the principles of Industrial Ecology [15].

The restructuring of the electricity market provides unique occasion for attract and spread cleaner technologies, particularly, renewable energy technology (RET), besides of attracting new players within new institutional and regulatory arrangements.[10] Old players tend to seek solutions within the existing technological regime, not necessarily investing on cleaner technology promoting sustainable society.

The structural changes on sector make possible to have another paradigm technological radically different technological system from that of conventional sources, like fuels and nuclear. The broad deployment of renewables would constitute a technological regime shift, inserted under cleaner production[11] conception. Renewable energy technology (RETs) differs not only in terms of source and technical characteristic, but also in their structural,[12] organizational, economic and social elements.

There is significant potential for increasing electricity access in isolated systems through the use of renewable energy. Renewable energy sources, such as PV, biomass, and small hydro, can be provided with local resources to remote communities, can guarantee the supply, have much lower environmental impacts, and allow energy independence [18]. According to Peskin and Barnes [19], there are many applications to Photovoltaic, mainly looking at the evolution of energy demands in the rural areas; one of its most notable aspects is the role and importance of electricity. Even at the lowest economic levels, just above subsistence, radios and torches can make a significant improvement in living standards and are widely used. The amounts of electricity involved are tiny, but are absolutely essential.

Household electricity consumption shows large local and international variations, as is the case in most features of rural energy use. These variations are broadly related to income. Families with higher disposable incomes tend to consume more electricity. The length of time a family has had a connection also has an effect family consumption usually grows with time. Consumption may also be significantly affected by costs, climate, culture, reliability of supply, and a variety of other factors. In some countries, for example, the utility sets such high building construction and house wiring standards for new consumers that electricity supplies are effectively restricted to upper-middle-class families who are likely to use a wide variety of appliances once they have access to the electricity supply. Other countries apply few such restrictions, and utility supplies are open to anyone who can afford the connection fee. This admits many poor families whose consumption is likely to be restricted to lighting [20].

The biomass stoves commonly used in developing countries, are not properly designed. As a result, they consume unnecessarily large amounts of fuel during cooking and other heating purposes and in addition, pollute the kitchen atmosphere due to incomplete combustion, which subsequently affects the respiratory system of the user. During the last decade, the first problem was given top priority and attempts were made to solve this design of biomass stoves properly. Some limited measurements indicate that, the improved design saves 50–80% fuel when compared with the traditional ones. But a very little attention was given, until now to the second problem, since 1985 prevention of kitchen atmosphere pollution by incomplete combustion of biomass has become a principal point of interest at the Eindhoven based Wood burning Stove Group [21].

In Brazil although the energy development in recently years, the firewood is the manly source used for cooking, however its use is more restricted to the agricultural areas or the urban communities of low-income. In the Amazonian case, the agricultural populations are citizens the sufficiently peculiar conditions: long distances, associates the great difficulties of locomotion and scarce monetary resources favor the use of local resources on the contrary of modern energy source [22].

Regarding the context Amazon, as the fuel (firewood) as far the equipment (stove) are local solutions, with big energetic waste and produce a lot of smoke. Actually, some studies of implantation of efficient stoves[13] (eco-stoves) in the rural area are under development, but slowly, although its potential market[14] (substitution).

Despite of the current Universalization Program in Brazil considering the use of efficient bulbs, there are no clear strategies of orientation to isolated communities about the use of energy of an efficient way.

In order to encourage sustainable development and the poverty reduction around the world in the future, today, the society should reflect about conceptual, theoretical and practical changes to ensure sustainable life-styles for our society. The sustainable development has to be understood like a journey, not as a destination.

4. Methodological aspects and fieldwork

There are few studies in the available literature about the relation between rural electrification and poverty reduction. When studies do exist, their scope of analysis is limited and usually restricted to experimental projects. Besides that, according Gunther and Harttgen [24], the poverty measures most established only assess the current poverty status of households, ignoring poverty dynamics over time.

Poverty should not be seen only in terms of income, considering that poverty has many faces, i.e. it extends to other spheres. Although it is repeatedly dealt with as deriving from lack of income, poverty should in fact be perceived as a multidimensional phenomenon, including, *inter alia*: physical weakness (sub-nutrition, lack of strength, precarious health, incapacity, high rate of active adults who are dependent on others); isolation (isolated location, ignorance (lack of education), lack of access to information or knowledge); income (lack of income); energy (electricity etc.), (lack of energy); vulnerability (increased exposure to natural disasters), impotence (choices, adaptation).

The studies related to mitigating poverty usually conceive of the term "poor" in relation to income. But it is not always possible to have all available data and, when data are available, to make sure they are reliable. One of the alternatives used refers to energy consumption[15] as a way to distinguish the "poor" from the "non-poor".

The debate surrounding the definition of energy poverty arises from the notion that poverty in a society is unacceptable. The

[10] Environmental pressures seem to provide a significant impetus for change in the selection environment and subsequently in the technological options [16]. In the long term, the criteria of zero or neutral CO_2 emission can be one among others obligations for utilities according to regulatory agency. According to Klemes and Huisingh [17], one of the important aspects of cleaner production is minimizing emissions. Besides the already mentioned CO_2 emissions that must be substantially reduced, there remains much that must be done to also reduce emission of SO_X and NO_X. Other important feature of cleaner production is minimization of wastewater.

[11] Cleaner production refers to the decrease in the waste generation and to the development of a product that causes a reduction of environmental impact throughout its life cycle [15].

[12] The low spatial density of their flows favors decentralized organization of production and constitutes a critical challenge for regulation and distribution [16].

[13] Traditional stoves are very inefficient and unhealthy.

[14] The heavy dependency on unmanaged biomass sources has created numerous socio-economic and environmental problems. This has led to massive deforestation and allied problems like soil erosion and loss of biodiversity. Besides, by tradition, the women shoulder the responsibility of wood collection, having been observed to carry more than 35 kg of firewood over distance of up to 10 km [23].

[15] For example, in Senegal, the income of consumers is so low that they use electric energy only for lighting. Such consumers are considered "poor" [5].

poverty line defines a minimum, and, if there is agreement as to the principle that the existence of people below this level is unacceptable, it is to be hoped that the society in question will apply the necessary effort to endure that all its members are above the minimum level.

When the insufficiency of income is analyzed, it is possible and laudable to transfer the income of the wealthiest groups to the poorest, in the context of promoting equity, so that when the poorest individual reaches the level of resources of the next poorest, they both then receive resources (in the same proportion) until they reach the level of the next poorest (moving upwards) and so on. In relation to income, equalization mechanisms involving transfers from the richest to the poorest are common, based on the principle of reparation. In relation to energy equity, however, this mechanism is generally neglected by those who formulate energy policy.[16] According to Birol [25], this issue when he states that energy economists have not addressed the challenges of energy poverty, in particular in the world's poorer countries.

It is necessary, drawing the poverty line, to define who is 'poor'. There is no general consensus as to the minimum amount of energy necessary. Establishing this total requires a priori, a value judgment in order to establish the hierarchy of energy choices in the light of the reality to be studied. The formulation of this value judgment, as to the minimum necessary for an individual or family group, is normally taken into account the living conditions of the other individuals.

It is essential, in order to draw the energy poverty line, to understand how the energy sources are used, given that the segment to be studied relates to those who are vulnerable, in socio-energy terms. It is possible to indicate that with an income increase, families tend to opt for more modern methods of cooking, heating, lighting and use of home appliances products. The literature relates the transition of energy (source/function) to income, although the demand of lower income groups for energy is restricted to cooking, heating and lighting. Given that, the absence of access to most modern sources of energy of this population group, resorts to biomass, thus, severely limiting the improvement of the quality of life and the productive potential of population. This demonstrates that, without public intervention i.e., in the absence of expansion of the access to electricity, this population will remain trapped by energy poverty.

As soon as this transition will occur, remains undefined i.e., this behavior depends on the capacity to pay, as well as the availability of the energy and the cultural preferences of the potential consumers. In general, this process is gradual, and not necessarily linear. In certain regions of Africa, firewood is also used for external illumination, and is gradually being substituted by electricity when electric energy becomes available to the dwelling. In the hot and humid rural regions of Brazil, firewood is burnt outside dwellings in order to repel the mosquitoes that infest the region. This behavior remains unaltered, for cultural reasons, even when the access to electricity on a safe and regular basis is provided.[17]

It is essential to expose energy poverty approaches, like: people who do not have regular and safe access to electricity; family spends over 10% of their income on energy and to estimate basic energy needs.

The third approach about estimating basic energy needs has been gaining ground in the literature. However, according to Pachauri et al. [28], there is no consensus yet on the question of minimum amount.

It is relevant to evaluate the total amount of energy realistically necessary in Brazil in order to meet the demand for lighting, heating and cooking. Bearing in mind the lack of information available on the energy profile of rural populations, without mentioning the effects on the reduction of energy poverty of government policies on the expansion of access to electricity, it was necessary to undertake fieldwork. Information was gathered in order to draw up an energy diagnosis of the population prior to access to safe and regular electricity, and then again 3 or 4 years later.

The fieldwork was undertaken via the application of structured questionnaires, between 2000 and 2004. The interviewer underwent training in the objectives of the research, the methodology, and the completion of the questionnaires, prior to visiting the region. The researched sample was considered to be universally representative, in terms of the issue being examined, of the beneficiaries of Brazil. The sample was random, being used in the first and second stages, respectively, of the information gathering, thus guarantying a reliability rate of over 95% in respect of the inferences drawn.

The existence of external factors cannot be considered an impediment to the evaluation of the results of government action in promoting access to electricity. In terms of methodology, the use of a random experimental drawing of the sample, together with a control sample, is advisable, despite being more onerous and time consuming. The control sample must have characteristics which are similar to the population affected by the government policies, including, for example: demographic, geographic, social, environmental, economic and energy characteristics, etc. Strictly speaking, the only difference between the samples should be that one was subject to intervention (electrification) and the other one was not. The control group was included in the fieldwork in both phases, in an effort to isolate effects other than the access to electricity.

Regarding data, they were collected in 21 states of the Brazilian Federation and considered two moments in time, i.e. prior to having access to electric energy (first phase) on a regular and safe basis, and 3 years following access (second phase). As far as the samples are concerned, they were classified and analyzed into two types:

- Electrified sample—set of rural households that were part of the national rural electrification program;
- Control sample (or non-electrified)—set of rural households that were not part of the national rural electrification program.

The pertinent information for the electrified sample amounts 17,102 rural households surveyed. They were divided into 8888 in the first phase and 8214 in the second phase. Regarding the control sample, the amount is 2885 rural households, divided into 1195 in the first phase and 1690 in the second phase. However, the division was made according to no information, the valid electrified sample would reach the level of 11,704 rural households surveyed, divided into 7722 in the first phase and 3982 in the second phase. Regarding the valid control sample, the new amount is 1271 rural households, divided into 452 in the first phase and 819 in the second phase.

With field data regarding the control and electrified samples in hand, it is possible to evaluate whether the energy changes

[16] The energy wealth issue deserves comment, although it is not the purpose of this study. In developed nations in particular, by the climate changed spot, the governments should strongly encourage the population to limit their consumption, considering a limit per household or per capita, applying disincentives for use above a certain limit and thus reducing the pressure on the environment.

Spreng [26] suggests per capita consumption of 2000 W as the limit, indicating that this level is compatible with sustainable development.

[17] According to studies carried out in South Africa by Mudubansi and Shackleton [27] on the consumption of firewood before and after electrification, firewood was used for cooking, prior to electrification, in 99% of the dwellings, in 71% for external heating of the dwelling and in 29% as raw material for ironing clothes. Following access to electricity on a regular and safe basis, the consumption of firewood for cooking was reduced to 96% of dwellings, with 5 % using firewood as a source of heating external to the dwelling and 0% using it as raw material for the ironing of clothes.

Table 5
Average energy consumption for all sources (GJ/year)—electrified × non-electrified.

Energy	Electrified sample	Non-electrified sample
First phase	14.16	17.30
Second phase	16.60	12.70

Source: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ ELETROBRÁS [29].

occurred resulting from the process of rural electrification. It ought to be emphasized that the analyses were concentrated on comparing the phase before having access to electric energy (the first phase) to the situation after the arrival of electric energy (the second phase). As for the control sample (non-electrified) specifically, its objective is to compare the natural impact resulting from time, context and conjuncture with the impact resulting from the electrification and captured in the other two samples. As such, the effects resulting from electrification and the effects resulting from other factors are isolated.

Similar to the concept already divulged by the literature on the topic of income poverty (poverty line), the task of the present article is to unfold this concept for the energy area. At first, the topic of energy misery was computed.[18] Energy misery represents the least amount of energy necessary to guarantee human survival. It is equivalent to 30 kg of firewood per month for a family of four persons, amounting to a total of 4.6728 GJ/year per family (energy misery line). The assumption is that below this value, survival itself is at risk, given that every family group requires a minimum of necessary energy to satisfy their basic necessities, as for cooking, among other purposes.

The concept of energy poverty line presented here, differs with respect to the amount of values indicated in the literature, despite a continuing lack of consensus as to the amount of energy necessary. The present study is based upon the assumption that the energy poverty line is a variant of the energy misery line, i.e. the consumption of those above the energy poverty line would be higher than 9.3456 GJ/year per family. In addition, it is worth emphasizing that the values presented are the result of initial studies made by the Electric Power Research Center[19] [29,30] on the energy profile made in the rural environment of Brazil. As an illustration, satisfactory but not ideal consumption of energy for a family in the country's rural regions would be 44.9892 GJ/year, when considering an energy basket of consumption projected at 128 kWh/month of electricity, 13 kg of GLP/month, 36 l/month of gasoline and 43 l/month of diesel fuel. The aforementioned basket was compiled by means of empirical field observations based on the energy consumption profile of about 9000 rural properties/households.

The results to be presented are restricted to the energy question. However, it is known that other factors must be evaluated. This is how we can gather a set of information able to guarantee, with the highest degree of reliability, what the real changes that occurred in the *modus vivendi* of rural people after the arrival of electric energy were.

5. Energy poverty study

Table 5 displays the values of average energy consumption, and considers all the sources per year between phases, and separates the properties between electrified and non-electrified ones. In the electrified sample, it can be observed that, in absolute terms, changes occurred in average energy consumption in the first and second phases, shifting from 14.16 GJ/year to 16.60 GJ/year. When analyzing the non-electrified sample, one can notice a drop in energy consumption between the first and second phases.

By performing an average energy consumption difference test,[20] between phases, in the electrified as well as non-electrified sample, such differences for the two samples proved to be significant. Therefore, it can be asserted that changes occurred in energy consumption for the electrified sample.

Based on Graph 2, it is possible to observe the composition of the energy basket prior the access to electric energy and after the access to electric energy, and thereby assess the respective changes. In the first phase, energy consumption was concentrated in the following triplet: GLP, firewood and diesel, in which the sum of the share reached a level of 90%. When analyzing the phase after the access to electric energy, the participation of the trio reaches 65% of the energy basket. It is worth highlighting also, the fast penetration of electric energy reaching the level of 34% of the energy basket.

When observing Graph 3, it is possible to confirm the composition of the energy basket of the non-electrified sample through time. Regarding the GLP, firewood and diesel triplet, there was a large change in the period analyzed, though the triplet still did maintain a considerable share. That is, in the course of the period analyzed the share of these items dropped from 94% to 84% in the energy basket.

It should be noted that despite not reaching the initial expectation of a considerable increase in energy consumption, this was also limited by the studied population's available income, standing at roughly US$ 238/month per family.

Table 6 shows per capita energy consumption values (GJ/year) between phases and per sample. A positive change can be observed in the thresholds of average consumption between first and second phases of the electrified sample, between 5.16 GJ/year and 6.65 GJ/year, respectively. On the other end, a negative change in consumption is shown, between the first and second phases, with respect to the control sample. There was a drop from 6.91 GJ/year to 5 GJ/year. When performing the statistical test of average difference, the changes were confirmed.

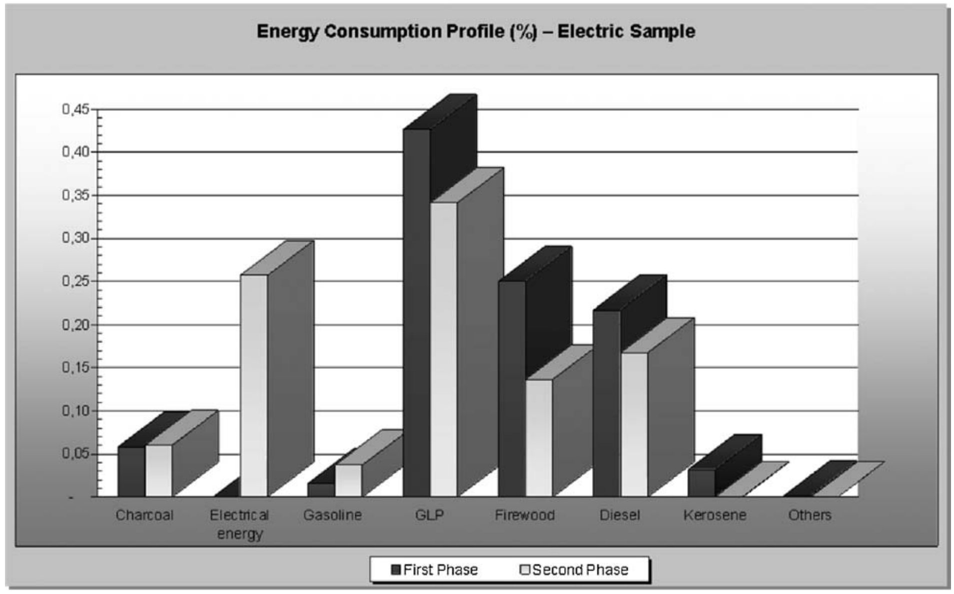
Accordingly, here is the picture of the data on energy poverty for Brazil. Graph 4 indicates the percentage of energy poor prior to the access of electric energy and following the rural electrification, especially for the electrified sample, wherein one can notice the drop in quantity of persons who do not have the minimum availability of energy to guarantee an adequate livelihood, that is, inserted into the concept of sustainable development. Between the observed phases, there was a drop in percentage of persons considered energy poor from 37.17% to 26.34%.

In parallel, Graph 5 points to a reduction in percentage of energy poor for the non-electrified sample, which dropped from 45.64% to 41.48% during the period analyzed. However, such a result has a lower amplitude when compared to the electrified sample. It

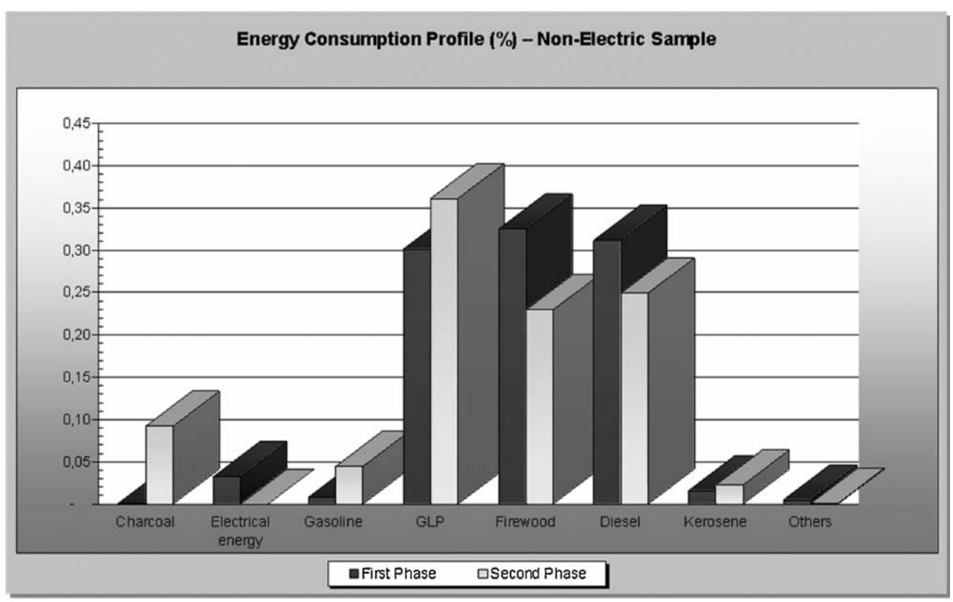
[18] In the present study, the calculation of energy poverty is made by considering per capita data, with the following values: energy misery – consumption below 1.1682 GJ/year; energy poverty – consumption below 2.3364 GJ/year, whereas an indication of satisfactory consumption would be 11.2473 GJ/year.

[19] The results presented were descendant from a broader study developed by CEPEL/Eletrobras with the aim of evaluating the economic, social and environmental changes that followed the implementation of the rural electrification programs in 21 of 27 States in Brazil.

[20] To test the hypothesis as to the equality of the averages of a determined variable between the phases surveyed, statistic average-difference tests were used. In the result, test significance is observed when Sig. 2—tailed/*p*-value in the event of the result being greater than 0.05, the equality hypothesis is invalidated for a reliability interval of 95%, i.e. the equality hypothesis is rejected. The conclusion drawn is that the average difference between the variable phases in question is statistically significant.



Graph 2. Energy consumption profile–electric sample. *Source*: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ELETROBRÁS [29].



Graph 3. Energy consumption profile–non-electric sample. *Source*: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ELETROBRÁS [29].

indicates that electric energy was determinant for the reduction of this contingent, although it was not the single factor.

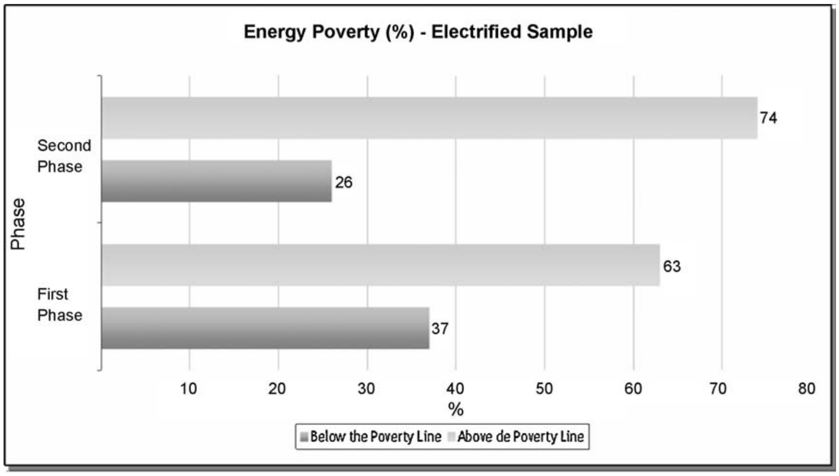
Such results confirm the initial expectations on how the contingent of persons below the energy poverty line was reduced between the phases. Despite how providing access to electric energy is the main slope to eradicate electric exclusion and mitigate energy poverty, there are nonetheless aspects of income limitation and biomass availability interacting directly with the result shown. It is important to exemplify the electrified sample in which there was an increase in consumption of electric energy and a decrease in consumption of firewood, GLP and diesel, in addition to a virtual absence of kerosene consumption. When considering the non-electrified sample, an increase in charcoal, gasoline and GLP consumption was observed.

Finally, such results indicate that rural electrification, in the Brazilian context, enable a positive energy impact on the energy consumption increase as well as on the consumption distribution

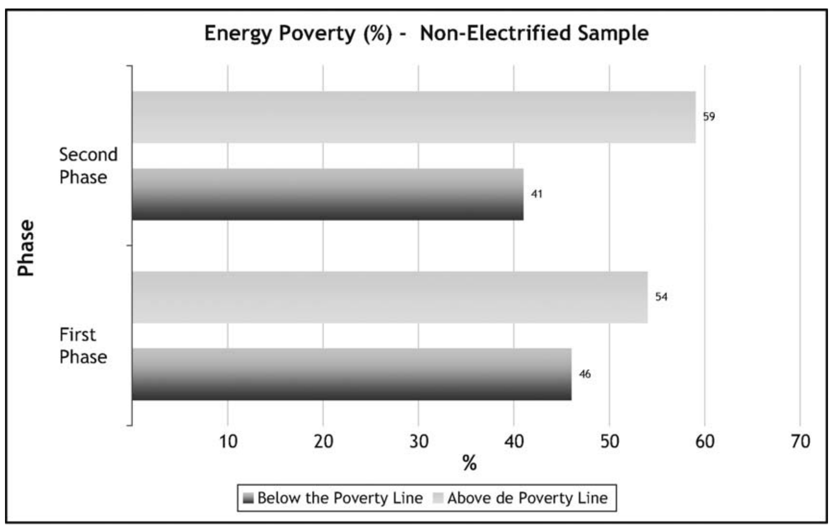
Table 6
Energy consumption per *capita* (GJ/year).

Energy	Electrified sample	Non-electrified sample
First phase	5.16	691
Second phase	6.65	5.00

Source: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ELETROBRÁS [29].



Graph 4. Energy poverty–electrified sample. *Source*: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ELETROBRÁS [29].



Graph 5. Energy poverty–non-electrified sample. *Source*: Own elaboration based on the IMPAR Version 2.3 System data CEPEL/ELETROBRÁS [29].

improvement (lower concentration of consumption). A reduction in the percentage of the so-called energy poor is also a positive result.

6. Conclusion

Recent reforms in Brazil and the world have sought to reduce the social deficit with respect to exclusion from electricity. Different paths of reform can be observed in the world. It should be noted that the reforms were predicated upon the ideal presuppositions of lesser government participation in the economy, whether that be through the process of privatization, the creation of a regulatory agency, the liberalization of markets, an insertion of independent producers or the creation of an agency responsible for rural electrification. However, in spite of the efforts made, few of them are aimed at universalizing the access to electric energy in the world and, by extension, to increased per capita consumption of electric energy.

It is should be pointed out that in Brazil, the first cycle of sector reforms was driven by the ideal of the minimal State. In the second cycle of reforms, begun in 2003, the actions were driven by the maintenance of a regulative Stat. This latest cycle has also seen as an initiative to resume a planning capacity that involves the creation of a new institutional arrangement with a broader social agenda.

When an assessment is made of the average energy consumption during the period, a statistically significant increase was observed, rising from 14.16 GJ/year to 16.60 GJ/year. Meanwhile, when analyzing the group that did not have access to electric energy, one can observe a drop between the analyzed phases, from 17.30 GJ/year to 12.70 GJ/year. Such results indicate that there was indeed a change in behavior in the amount and profile of consumption among the families analyzed. These families modified their energy basket, in which electric energy rose to 34% of the share. Also, these families became more intensive in their consumption of energy, which went hand in hand with a reduction in local pollution.

Despite the positive change in per capita consumption of energy between the phases from 5.16 GJ/year to 6.65 GJ/year, when considering all sources, such an amount can be emphasized as still lying far from the required values indicated in the literature for a significant improvement in life quality to be observed *de facto*. The reference for the latter points to a correlation between per capita energy consumption and the Human Development Index (HDI), according to which there is stagnation in the HDI with consumption below 22 GJ/year.

What the analysis of the contingent of energy poor between the phases reveals, is a significant drop among these poor, from 37% to 26% of persons surveyed in the period under consideration. By analyzing the control group, similar behavior was also observed, with a drop from 45% to 41% in energy poor. Nonetheless, the amplitude of the drop of those who received electric energy was much higher. This result clearly indicates that access to electric energy was an important factor to reduce the contingent of energy poor, although it was not the only.

The rural electrification program in Brazil has had a significant impact. It has not only greatly improved coverage but has also changed the way things are done in the field. It has shown that it is possible to achieve rural electrification.

The universalization of electric connection has to consider as window of opportunity so as to foment national industry, particularly the cleaner technologies, speeding up renewable energy technology[21] in the Brazilian energy system. According to Moss [31], among all countries, Brazil is the most important one considering the usage potential of renewable energy. Brazil has a huge coast area where wind energy could be produced easily and also a lot of solar radiation, besides these, we have an enormous potential to produce biomass energy. It is important to have, however, a conjunction of all renewable sources as they are incredibly complementary.

It is important to advertise that the universalization of electric connection has its biggest barrier on the social problems and not only technological. Although it is still not equated on the management connection model to be used on the isolated communities in Brazil, independent on which strategy applied, it must considerate: new regulatory arrangements, encouraging a new national industry from renewable energy technology and altering the set of investment criteria of enterprise, for example, including zero or neutral CO_2 emissions; support to innovation technologic; scientific research as way to propose regional solutions; the goals of energy efficiency; adequate rates; community interaction; and, when possible, local incoming policy, increasing the effective of the reduction poverty action in all of its faces.

Finally, the universalization of the access to electric energy provides a window of opportunity to reflect the change of the technological paradigm of the centralized energy generation to the decentralized generation, in search of a sustainable society, in line with environmental concerns and their consequences Global Warming, Water insecurity, Ozone layer destruction, Toxic substances, Energy insecurity, Poverty and so on), favoring the less developed populations, still trapped by the energy poverty.

[21] Nowadays, the big bottle-neck of solar industry is supplying silicon, fundamental raw-material so as to produce the solar plate. Brazil is abundant of natural resources, in case of silicon, is the biggest world producer, can be able to be an important export country. At the same time, the production cost, for example, plate solar in Brazil and Germany are totally different, can be three times lesser in Brazil [31].

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